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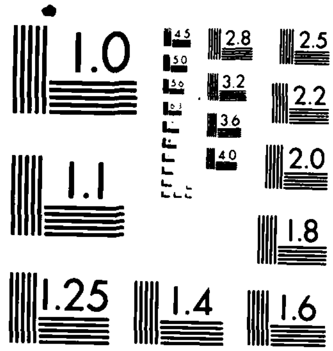

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Local Area Network Implementation Plan

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A plan for local area networking at The Aerospace Corporation is described in this document. The initial network will link several existing computers in order to allow direct communication between them and with the ARPANET. This will facilitate the sharing of resources (hardware and software) among different groups with common interests within Aerospace and will allow access to the unique resources of the ARPANET.

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SUMMARY

In this document, a plan is described to deploy a local area network linking together several dispersed computing facilities within The Aerospace Corporation in order to promote the sharing of these internal resources and to provide access to the unique resources of the ARPANET. This plan has grown out of two independent efforts to meet particular communication requirements: (1) In support of VLSI research there is a need for the CAD VAX in D8 to communicate with the ISRO VAX in A2 and with the ARPANET; (2) A "Labnet," linking together several existing laboratory computers and a new medium sized computer (called the "Lab VAX"), is required to satisfy the general resource sharing needs within the Laboratory Operations. The proposed local network meets these needs.

The authors
~~We~~ propose the use of two technologies for the implementation of this network. proNET (a token passing ring using various media including fiber optic links) has been selected to provide interbuilding communication. This selection was made because of its relatively long range (2.5 km) and because hardware is available to use fiber optic cable as a medium. Ethernet (a contention bus using 50 ohm coaxial cable) has been selected as the intra-building network because of its reduced cost and wide vendor support. The introduction of Ethernets should be taken into account during the procurement of new computing equipment (minicomputers, personal computers, word processing systems, etc.). New devices which are compatible with or contain interfaces to Ethernet can benefit from network services while others cannot.

Prior to deployment of the components at least the following cables must be present: (1) A3 to D8 - use of an existing spare fiber optic pair, (2) A3 to A2 - new twin-axial cable, (3) A3 to A6 - existing coaxial cable, and (4) A3 to 130 - new fiber cable. The first three cables are apparently easy. The fourth requires the removal of unused security wiring from existing conduit and pulling new cable. When other buildings require connection, then additional cable will need to be installed or be made available for use in the local network.

The initial network will use proNET components to link together the CAD VAX in D8, the ISRO VAX in A2, the APL PDP 11/34 in 130, and a PDP 11/23 Gateway into the ARPANET. The plan calls for eventual connection of the IPD mainframes and two additional types of minicomputers as well as some personal computers, word processing systems, and other terminals. The initial four node network is scheduled for completion by April 1983. A plan consisting of five phases is outlined in section 3.

The capital expenditure for the initial network is between $30,000 and $32,000 for hardware

(excluding cabling) and between $15.000 and $20.000 for software. Incremental hardware costs (excluding interbuilding cabling) for extension of the network are as follows: proNET only to each additional building - $2000-3000; proNET to each additional computer - $3150; Ethernet in each building - approximately $12.000; and Ethernet to each additional computer - $2000-3000. The per node cost of Ethernet ($2000-3000 today) is expected to drop rapidly in the future. Many products already exist with built in interfaces to Ethernet or are planned for the near future.

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1. INTRODUCTION

There are a number of computing resources scattered about the corporation, many of which need to communicate in some way. One classic example is the laboratory computer which has power enough to provide experiment control and data collection but lacks sufficient power tc reduce and/or analyze the data collected. For number crunching one needs a much more powerful machine. The traditional approaches to communication between small and large machines (i.e., magnetic tape, low data rate dial or leased telephone circuits, etc.) are cumbersome, time consuming, often fraught with incompatibility problems and sometimes more expensive than direct connection through a local area network (LAN). This example demonstrates the crux of the problem that computer networks in general attempt to solve through universal access to shared resources. From an individual's point of view, it is be best to have sole access to all the computing power needed to accomplish a task in the shortest, most convenient way. The problem with this approach is that computers adequate for specialized tasks such as number-crunching or graphic display manipulations are too costly. Therefore it is cost effective to centralize expensive resources and provide a convenient way of sharing those resources among those desiring to use them.

The concept of centralizing expensive resources is not new. It has been done effectively within Aerospace in many areas: the central library, the photo lab, the reproduction centers, to name a few. Even the major computing resources are centralized in the large computers of the IPD. A computer network aims to provide convenient access to these central resources as well as to other dispersed or unique special purpose resources being deployed throughout the corporation (e.g., CAD/CAM, special graphics, etc.). Along with internal resource sharing, the network will provide convenient access to the several unique resources of the ARPANET. Among these resources is an automated VLSI fabrication facility as well as electronic mail facilities to many of our Air Force customers.

In addition to the need to connect these existing resources, new resources will require a high-speed local area network in order to provide the intended service. Review of the computing requirements of the Laboratory Operations and currently available resources has lead to the decision to acquire a medium sized computer. This machine is commonly referred to as the Lab VAX because a VAX is an appropriately sized machine for this purpose The Lab VAX is expected to be purchased in FY 84. The Lab VAX will be shared by laboratory researchers throughout AGO. It will be used for general computing within the laboratories and will provide a resource with which to control experiments and reduce the data collected in the various laboratories. This latter application requires direct high-speed computer-to-computer communication (i.e., a local area network).

This document presents the implementation plan for a local area network within The Aerospace Corporation to allow the sharing of internal resources as well as the resources of the ARPANET. We first discuss some general concepts of local networking, give some particulars regarding the Aerospace Corporation and highlight the features of the selected systems: proNET and Ethernet. The details of the plan are then presented in section 3. This includes the cabling required prior to implementation and the initial configuration details.

There are some issues which this document leaves unresolved. Among the issues that we do not attempt to cover in this document are the following: (1) the privacy and security of data, (2) use of the network for secure voice communication, (3) the connection of dumb terminals to the network, (4) the connection of word processing systems to the network, (5) the connection of personal computers to the network, and (6) the connection of facsimile devices to the network.

2. LOCAL NETWORKING

In this section we attempt to answer the following questions. What is local networking? Why is The Aerospace Corporation interested in a local network? What services does a local network provide to the user? Does the Aerospace physical plant support the implementation of a local network? What candidate networks emerge to satisfy our particular needs?

2.1 CONCEPT

A local area network (LAN) provides high speed (between 10.000 and 100.000.000 bits per second) data communication between a set of computers over inexpensive transmission media in a small geographic area (from several meters to a few kilometers in diameter). The computers attached to the network are called "hosts." The network spans the gap between a computer bus and a long-haul (inter-city) computer communication network both in distance and data rate. The purpose of a LAN is to allow convenient, inexpensive, on-line communication between proliferating computing resources which are becoming more and more distributed. This communication capability gives users the ability to share hardware. software. and data.

2.2 ADVANTAGES IN THE AEROSPACE ENVIRONMENT

The Aerospace Corporation. like other technology companies. is experiencing tremendous growth and dispersion in its population of computing resources. This is primarily because these resources have undergone drastic price reductions over a short period of time. This price drop is continuing. We are moving out of the mode of the single totally centralized computing facility. Indeed. we have already purchased many minicomputers and personal computers. We are in the process of attempting to determine some standards prior to the anticipated purchase of a large number of personal computers. Some day. not far away. costs will be such that each person with computing needs (almost everyone) will have a personal computer on his/her desk. This will not eliminate the need for central resources for large-scale computing. mass storage. and special purpose I/O facilities such as typesetters. plotters. and the like. However. it does mean that there will be a strong need for these distributed facilities to communicate directly. The need exists now and will become increasingly acute as more and more distributed computing resources are put in place.

The advantage of local networking to Aerospace (and to other corporations) is in the saving of personal time. An example will illustrate what is meant.

Suppose I have just produced some data on my local computer which needs to be plotted on a graph. I could plot it by hand. which would take perhaps 2 hours of my time and the result would not be of sufficient quality to publish. I could submit it to a artist and wait a few days for the result. which would likely require some modification. What I would like to do is have it machine plotted so that I might see a reasonably good quality plot in a short time: after I have seen it I might want to adjust the scale to show detail in a certain area. However. today there is no plotting capability available directly to my local computer. Therefore. I must write the data on magnetic tape (in the proper format). hand carry it to the computer center. and pick it up when the plotting is finished (which completion time I must estimate). This process takes at least 1 hour (after I've learned how to do it).

If a local network were in place the scenario might read as follows. I would ship the data directly to the plotter (or to the computer which controls it). which would take 3 or so commands at my terminal. I would receive a message at my terminal advising me that the output was ready to be picked up. I would then go pick it up. This whole process would take about 15 minutes of my time. at least 12 minutes of which would be spent walking to pick up the output. With this kind of time saving it wouldn't take long for the local network to pay for itself.

This specific service will not be available immediately following the initial installation of the network. but a local area network makes it possible and if the demand is there. the service will be available soon. This scenario was played many times over on the ARPANET by one of the authors in the preparation of his dissertation.

2.3 SERVICES PROVIDED TO THE USER

The services to be provided to the user are those familiar to users of the ARPANET: (1) remote interactive access to a variety of computers. (2) sharing of data and software through file transfer facilities. and (3) electronic mail. These services will be available immediately after the local network is installed. The plan calls for obtaining the software to provide this level of functionality at the outset.

Through remote interactive access one can use a remote system as if one is connected through a local terminal. This allows access to unique hardware and/or software that is available in the network. In our case. for example. this hardware and software would include the CAD/CAM/CAE and graphics tools on the CAE VAX: the text editing. text formatting. and Interlisp facilities of the ISRO VAX. the VLSI fabrication facility and the symbolic manipulation tools (MACSYMA) on the ARPANET.

Remote access is also possible through dial (or leased) telephone lines at lower data rates than a local network can provide. What sets a (local) network apart from other forms of communication is the direct machine-to-machine communication. This typically is some form of file transfer (FTP) in which data (or code) is transferred from the file system on one machine to the file system on another

machine at high speed. This allows generation of data at one node and processing of that data at another node in the network, remote printing of locally prepared text, etc.

Electronic mail systems provide a service with advantages over both the telephone and normal written forms of human communication.[1] One advantage over the telephone is that both (all) parties do not have to be available at the same time for information to flow. Electronic mail is less formal. much quicker than typical written communication (memos and letters), and can flow directly between the interested parties.

2.4 LOCAL AREA NETWORK COMPONENTS

A (local area) network consists of a collection of transmission media and a set of hardware and software components which implement a (layered) set of protocols in each host allowing communication between software entities, called processes, to occur over the media. We discuss those components in this section.

The International Standards Organization (ISO) has developed a reference model for Open Systems Interconnection (OSI). The OSI reference model[2] describes a conceptual architecture of protocols by which processes in two heterogeneous computer systems may communicate. The model partitions the functionality of communication into seven layers. Each layer provides a well defined set of services to the layer above it. The services provided at each layer are listed below.

1. Physical Layer - provides the transmission (and reception) of a bit across the physical media.

2. Data Link Layer - provides the (reliable) transfer of blocks of data using the physical layer to send and receive bits.

3. Network Layer - provides the routing and switching of packets between hosts using a sequence of links and subnetworks.

4. Transport Layer - provides reliable ordered end-to-end exchange of data between hosts using the network layer to send packets.

5. Session Layer - establishes, maintains and breaks communication dialogs which exchange bit strings using the transport layer.

6. Presentation Layer - manages and transforms the syntax of structured data objects being exchanged.

7. Application Layer - performs the mechanics of information exchange between application processes.

There exist several standard protocols for layers 1 and 2. The specific choice depends largely on the medium chosen. These two layers are typically implemented in hardware. Standards also exist at higher levels, and these typically are implemented in software. We have chosen to use the DoD standard protocols for levels 3 and 4. These are referred to as the Internet Protocol (IP) and the Transmission Control Protocol (TCP) respectively. Using these particular protocols greatly facilitates communication with the ARPANET (which is one of our primary goals). With wider acceptance of standards at higher layers, we will see hardware implementations emerge. IP and TCP have been implemented on several large computers and minicomputers as well as the Z8000 microcomputer.[3]

2.4.1 Media

Local area networks have used a variety of media over which to send signals. Included in this list are: (1) twisted wire pair, (2) twin-axial cable, (3) 75 ohm coaxial cable, (4) 50 ohm shielded coaxial cable, (5) fiber optic cable, and (6) the atmosphere. Several topological arrangements of the media have been used.

The topology of a local area network can be classified as being a (1) bus, (2) ring, (3) star, (4) tree, or (5) mesh. In a bus topology, the media "passes by" each host. Each host attaches to the bus by breaking the cable (generating a series of point-to-point links) or by tapping the cable in some way (i.e., using a single unbroken cable). The bus has two ends. A ring is simply a bus with the ends connected. A star connects each host to a center node through a point-to-point link. A tree may be thought of as a set of buses connected together such that no loops are formed. Finally, a mesh is a arbitrary set of connections between hosts.

Signaling over the media may be done at baseband (i.e., a sequence of square pulses) or modulated on a higher frequency carrier. Typically Manchester encoding is used at baseband to ensure that state transitions occur at least once per bit time. Signals may be propagated in one or both directions in any topology, in principle. Typically, however, the bus is bidirectional, while the ring is unidirectional. The star and mesh are typically implemented with a set of full duplex (i.e., bidirectional noninterfering) links. The tree typically has a special node at the root of the tree called the head-end. Individual stations transmit on the tree with the signal propagating in both directions. The head-end then repeats the transmission out toward the leaves of the tree.

Access to the media takes several forms as well. Typically, within the context of local area networks, two types of demand multiaccess schemes are used: (1) contention and (2) token passing. With contention, a host may send a packet at any time (typically after listening for a short time as in

CSMA/CD). Contention schemes have mechanisms for dealing with the case when two (or more) hosts overlap their transmissions. With token passing a host may use the media only when it possesses a token. The token circulates the network providing some minimum level of service to each host.

2.4.2 Hardware

Commercially available local area network hardware implements the physical and data link protocol layers. The hardware is broken down into three main functional elements: (1) host specific interface (HSI). (2) controller and (3) transceiver. The hardware components of a generic local network are illustrated below in Figure 2-1. The host specific interface provides communication between the CPU and the controller by, for example, using the internal bus of the host machine. The controller implements the data link protocol. The transceiver provides the physical connection to the medium and performs the physical layer protocol functions. In the systems discussed below, these generic components are packaged in slightly different ways.

Figure 2-1: Generic Local Area Network Hardware Components

2.4.3 Software

As the hardware is divided to provide modularity, so is the software. The typical architecture consists of a "driver" at the lowest level, on top of which the lowest software protocol layer is built. Each successive layer is built on top of the lower layer.

As with any I/O device attached to a computer system, there is some software in the operating system to handle (or drive) that device. This software is commonly called a driver. In the context of a local area network, the driver software provides the data link services to the operating system. The driver is specific to the hardware interface and to the operating system. Drivers act as interface normalizers by providing a common set of services for each network to the network layer software. The network layer selects a particular network (i.e., driver) to use for any particular packet and is able to communicate to all drivers in the same way. Thus to connect a host to another type of specific network one need not reimplement the entire network layer. Only a new driver is required (as well as knowledge at the network layer of the existence of the new driver).

As stated above, we have selected TCP and IP as our internal standard protocols for layers 4 and 3, respectively. Software for these layers with ARPANET drivers is available for many operating systems. All systems connected to the ARPANET are required to have a running implementation of TCP/IP by 1 January 1983. Some of these implementations have had drivers built for proNET and/or Ethernet.

2.5 CANDIDATE SYSTEMS

We have used three basic ground rules to guide the selection of candidate networks. These rules are:

1. Fit the Aerospace environment;
2. Provide access to the ARPANET and
3. Use commercially available hardware and software.

The ground rules have lead us to two candidate systems. Ethernet and proNET are the only commercially available networks which have software available for TCP/IP/Telnet/etc.

2.5.1 Ethernet

The Ethernet is a broadcast coaxial bus oriented system providing 10 Mb per second of raw data rate and supporting up to 100 stations (hosts) along a kilometer of cable. The Ethernet employs carrier sense, multiple access transmission with collision detection (CSMA/CD) logic, all of which is implemented in hardware at the link level. Ethernet components are available from several vendors, including: ACC, DEC, DTI, Interlan, TCL, 3Com, and Xerox. Experimental Ethernets (3 Mbps) have been in use at Xerox PARC,[4] several universities, and in some Xerox commercial systems for several years. During the development of these experimental networks by Xerox, the term Ethernet was coined. The word now applies to all products, independent of vendor, which meet the Ethernet specification. That specification was developed as part of the three company agreement between Xerox, Digital Equipment Corporation (DEC), and Intel.

The notion of multiple access via contention was first introduced in the Aloha system at the University of Hawaii.[5] In that system all nodes shared a common radio frequency band. An external arrival of a packet (perhaps caused by a user typing a character) at a node caused that node to immediately broadcast the packet. If no other node tried to broadcast during the same (or overlapping) time period, then (ignoring other errors) the packet transmission was successful (i.e., the

data got through). A successfully received packet is "acknowledged" by a return transmission. If the sender fails to receive an acknowledgement, then the packet will be retransmitted after a random time interval. The retransmission delay is selected at random independently at each node so that nodes which have collided previously with one another will have a low probability of colliding with each other again. There have been three main refinements to this initial concept: (1) Slotted Aloha.[6] (2) Carrier Sense Multiple Access (CSMA),[7] and (3) Carrier Sense Multiple Access with Collision Detection (CSMA/CD).[8] A version of the latter refinement is what is used in Ethernet. The first refinement divides the channel into time slots equivalent to a packet transmission and forces transmission at slot boundaries. This means that collisions overlap totally thus reducing the likelihood of collision. In CSMA each node listens to the channel for a short time (i.e., one end-to-end propagation time) prior to sending a new packet. If the node senses that someone else is sending, then it waits; Otherwise, it is allowed to send. This further reduces the probability of collision in relatively small area networks (i.e., where packet transmission time is sufficiently larger than the propagation delay). In CSMA/CD a node listens both before and during the sending of a packet. If a collision is noted during transmission, then the transmission is aborted (stopped) and randomly rescheduled. This reduces the time wasted due to a collision. There have been several other extensions to these schemes, most of which are described by Tobagi.[9] Datagram level (packets) and message level protocol (TCP/IP) software for the VAX(s) (Unix and VMS) as well as other DEC PDP-11 systems is available from selected vendors, and expectations are for more generally available and improved software. The Ethernet specification has been accepted as a standard in the industry and currently provides the impetus for the development of readily available and inexpensive hardware and software. Unfortunately, combinations of software and hardware are not currently available for satisfying the interface of all the required Aerospace computer systems.

A typical Ethernet implementation employs a coaxial cable medium, a transceiver, a transceiver cable, a controller, and interface to a host computer. The Ethernet hardware is illustrated in Figure 2-2. The transmission medium is a low loss, well shielded standard 50 ohm coaxial cable. The transceiver provides the tap into the transmission medium, the collision detection logic, and the modulation/demodulation (Manchester encoding) of transmitted and received signals. The interface to the controller card is a transceiver cable (50 M maximum) carrying data and control signals as well as power to drive the transceiver. The controller card provides the buffering, address recognition, and interface to the host computer. Currently, controllers are available for Unibus, Q-bus, and Multibus.

The available software is very fluid since many vendors are currently implementing a variety of

Figure 2-2: Ethernet Hardware

components. Generally. drivers are available for most systems of interest to Aerospace. while only a selected few vendors offer higher level protocols (TCP/IP. FTP. Telnet. MSG) software. All the required software is not generally available for any of the local network options being considered. UNET. offered by 3Com. provides networking software for Unix based systems. In order to satisfy all of the Aerospace requirements. we will need a combination of software packages from multiple vendors and universities plus new software.

Ethernet (CSMA/CD) has very good performance at low channel load. few simultaneously active stations or short cable lengths. The performance of CSMA/CD is largely characterized by the parameter *a* which is the ratio of the one way propagation delay over the full length of the network to the packet transmission time. As i(a) increases. performance degrades. Notice that *a* increases as *cable length increases, transmission* speed increases. and/or packet size decreases. Performance is always good at light load and/or with few simultaneous active stations. The achievable throughput of individual hosts is likely to be significantly lower than the data rate of the cable. This is due to the implementation of the TCP/IP protocols and/or the internal bus or memory speed of the host more than to the inefficiencies inherent in CSMA/CD.

The Ethernet specification puts strict limitations on the size of an Ethernet. This is due to the delay constraints of the collision detection mechanism and to the power of the transceiver. A segment may be no longer than 500 m. One may join. at most. three segments via two repeaters (hardware is just becoming available for this operation). Remote repeaters may be used to join two segments which are no more than 1000 m apart (hardware does not now exist for this operation). This means that a purely Ethernet solution requires more than a single network.

Example prices (from 3Com except as noted) for required components are listed in Table 2-1. Each host requires one controller. one transceiver. one transceiver cable and TCP/IP software. The prices quoted are for quantity one. Please note that quantity discounts are available for both hardware and software. This is particularly true for software. For example. the UNET price drops to $2000 for each copy (even lower after 10 copies) after the initial $7025 for the first Unix system.

Table 2-1: Ethernet Example Costs

Ethernet Costs (3Com prices except as noted)		
Required per Host Connection		
Controller		\$1250-2400
Unibus or	\$2400	
Q-bus or	\$1750	
Multibus	\$1250	
Transceiver Connection		\$570
Transceiver and	\$450	
Transceiver Cable (15m)	\$120	
Total Hardware Cost per Host		\$1820-\$2970
TCP/IP Software		\$600-15.000
UNET Software (Unix only) or	\$7025	
Access-L Software (VAX-VMS only) (DTI)	\$15,000	
Public Domain Software (approx)	\$600	
Total Cost per Host		\$2420-17.970
General Network Components		
Coaxial Cable (15m)	\$150	
Terminator	\$20	
Repeater (Xerox)	\$1285	

2.5.2 proNET

proNET is a product of Proteon Associates, Inc., a small company based in Waltham, Massachusetts. Proteon holds the license from MIT, the developer of proNET. The license allows Proteon to build and market proNET components. proNET is a token passing ring local area network with a data rate of 10 Mbps. Software for link and physical level protocols as well as TCP/IP, up through Telnet, FTP, etc., is available for most PDP 11 and VAX systems.

proNET is a token-based ring architecture with some very positive features. The ring is configured as a "star-ring." This means that the ring goes out to and returns from each node to a "wire center." Topologically, the cable is a ring, but if there is trouble with any node or a break in any portion of the ring, the troublesome section can be eliminated from the ring by "cutting" it out at the wire center. The cutting is not literal but is done by relays which are triggered at the wire center by control signals (or the lack thereof) from the node. The wire centers are passive, not active, so they don't suffer from the disadvantage of a star where the entire network goes down if the central element fails.

The performance of a ring network is essentially bounded by the round trip delay around the ring

(i.e.. the time it takes for a bit to traverse the network and return to the sender CTL). This delay has two main components: (1) the "speed of light" propagation delay of the signals on the media and (2) the delay through the collection of CTLs in the network. The delay through one CTL is on the order of 1 μsec in order to give it enough time to detect the presence of a token. A random arrival from a host in an empty network would wait on average one half of the round trip time before being able to send. This time is always longer than the carrier sense time in Ethernet (0.2 μsec). Thus the performance of proNET in terms of delay under light load is slightly (on the order of a few microseconds) poorer than for Ethernet. proNET does. however. perform much better than Ethernet at higher loads. The observed throughput of individual hosts on a proNET is significantly less than the data rate of the network (as it is for Ethernet). This is due to the implementation of the TCP/IP protocols and/or the internal bus or memory speed of the host.

The use of a ring topology implies one-way circulation of messages. This facilitates the use of fiber optics as a transmission medium for proNET. Indeed. proNET offers four methods of connecting nodes: for short hauls of up to 100 m. twisted wire pairs are used: for distances between 100 and 300 m. twin-axial cable is used: for distances up to 600 m. 75 ohm coaxial cable pairs may be used: and for distances over 300 m and up to 2.5 km. fiber optic cable is used. proNET's range completely meets the *requirements for connecting the* AGO buildings.

Proteon supplies two interface cards per node: a controller board (CTL) (all alike) and a host specific board (HSB). proNET hardware is illustrated in Figure 2-3. Proteon presently markets interfaces for Unibus, Q-bus, and Multibus. For use with fiber optics. a pair of transducers. referred to as FL/WC/CTL "fiber link from wire center to controller." is required as shown in Figure 2-4. Proteon is currently working on a Hewlett-Packard interface (parallel-duplex). This is set to be released by the first quarter of 1983. Proteon is also looking into a Versabus interface.

Figure 2-3: Pronet Hardware

The CTL is a dual width DEC card which connects to the byte parallel HSB interface by a 50-pin cable. and to the ring transmission media. The CTL board handles network transmission/reception functions such as modem. serial-to-parallel conversion. repeater. address recognition. parity check. token management. bit stuff. and error timeouts. It also activates the wire center relays and has

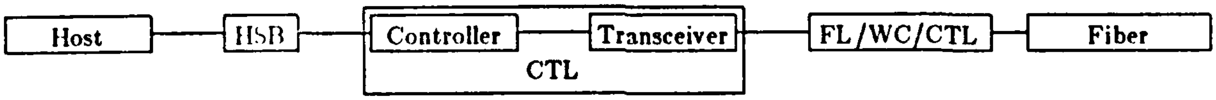

Figure 2-4: Pronet Hardware for Fiber Optic Cable

circuitry for self-testing under program control. The CTL performs hardware address matching against the 8-bit node address set by dip switches. One broadcast address is provided, leaving 255 available node numbers.

The proNET Unibus HSB in combination with the CTL connects any Unibus PDP-11 or VAX to the token ring. The HSB is a quad width board, and together with the CTL, forms a standard hex width module that plugs into a hex Small Peripheral Controller (SPC) slot in the Unibus backplane. The CTL and HSB can also be configured to use two quad SPC slots if necessary. The HSB is the communications controller. It does much of the work for the host computer: sequencing, buffering, and controlling. This is why there is a very low software overhead burden. The HSB contains packet buffers, DMA logic, and control logic. There are two packet buffers (2046 bytes each), one for transmit and one for receive. The DMA circuits and on-board packet buffers minimize bus and CPU overhead in sending and receiving messages.

The proNET hardware, in combination with any of the proNET software drivers, implements levels 1 and 2 of the OSI model. Drivers are available for RT-11 v4.0, RSX-11M v3.2 and v4.0, RSTS/E v7.1, and VAX/VMS v3.0. All drivers include source code, and only one license is needed for all machines on a network using each driver. TCP/IP software with proNET driver is or will be available for several systems of interest to Aerospace. Versions exist or are under development for PDP-11, Unix v6 and v7, BSD VAX Unix, and VAX/VMS. This software provides complete file transfer (FTP and TFTP), remote login (Telnet), and electronic mail (SMTP). We currently have the software for VAX-Unix from BBN. Software for VAX-VMS (currently with Ethernet driver) is available from DTI. TCP/IP software for RSX and RT-11 systems is being developed at Egland AFB for connection to the ARPANET. This software will be completed by January 1983. Mike O'Dell at LBL has committed to write proNET drivers for the VMS, RSX, and RT-11 software for their own proNET. LBL has VAX hosts running Unix and VMS, several RSX hosts, and a flock of SUNs (Stanford University Network) running Unix, which are all due to be linked by proNET. Their commitment to proNET seems real and deep. Furthermore, whatever they develop will be public domain software.

The proNET Wire Center (WC) allows the proNET ring network to operate as a star-shaped ring for

increased reliability and maintenance while simplifying cabling. Each WC can connect to 8 (WC/08) or 16 (WC/16) nodes or adjacent WCs. In a star-shaped ring, the ring exists inside one or several WCs and will loop out to active nodes. Each node is connected to the ring by a military-quality relay which is only operated by the node when the CTL is powered and the HSB has been given the "join ring" command. A power failure at one node will not bring down the network. In addition, nodes which find themselves to be faulty after digital loopback testing will not join the ring. The wire center requires no power itself, except for the small currents supplied by the CTL cards to activate their relays. All nodes are transformer-coupled so there are no DC connections between the cables or nodes. The wire center is roughly 9 x 13 x 6 in. and may be mounted on a closet wall. It requires no local power or air conditioning.

The proNET Terminal Interface Unit (TIU) interfaces dumb terminals to the ring. It can interface with 2, 8 or 16 RS-232C terminal lines. The software available for the TIU implements the DoD TCP/IP/Telnet protocols. The TIU is based on the DEC SBC-11/21 "Falcon" processor and a proNET Q-bus network interface. The 8 and 16 line units use DZV11 equivalents. Since the system has a Q-bus, any other Q-bus compatible network can be interfaced via the TIU. In particular this includes Ethernet! proNET can connect to an Ethernet via a TIU-2 with two cards in it: a proNET interface and an Interlan Q-bus Ethernet controller card. This makes it suitable for connecting to the CAD VAX in D8 and to the APL 11/34 in 130 via fiber optic cables, and to the ISRO VAX local Ethernet, for example. With special software, the TIU can be used to interface machines for which there is no HSB. This could include the HP 1000, the PDQ-3, and Speckhard's machine.

proNET hardware has been found to be very reliable. Users have had little or no trouble with running networks. In particular, a token network can get into trouble if the token gets clobbered. Most users reported no problem, saying that the net reinitialized itself without problems if they broke the ring and then reconnected it. Proteon Associates has been very responsive to user problems. The primary disadvantage of proNET is that it is not a standard product in the same sense as Ethernet because of the manufacturer support. However, proNET is selling very well.

proNET offers a connection to IBM computers via the Auscom 8911 Programmable Channel Interface. On the IBM side, the 8911 interface can be linked to any IBM selector, Byte MUX, or Block MUX channel via standard BUS and TAG cables. On the device side of the data path it can be connected to any Unibus or Q-bus device. The 8911 comes with the ARIES operating system that provides high-speed data transfer in a variety of interface configurations through the use of emulator and device driver software modules in the ARIES library. Data is transferred from the IBM channel at channel speeds. Data is transferred to the DEC computer at 1 Mbps at distances from 25 to 1000 ft.

proNET costs are listed in Table 2-2. Each host requires one CTL/HSB, TCP/IP software, and two connections to a WC. If the medium for that connection is fiber optic cable, then a fiber optic WC/CTL link is required.

Table 2-2: proNET Costs

proNET Costs		
Required per Host Connection		
CTL/HSB		$3150
CTL/HSBU (Unibus) or	$3150	
CTL/HSBQ (Q-bus) or	$3150	
CTL/HSBM (Multibus)	$3150	
CTL to WC		$0-2800
No cost for wire connections or	$0	
FL/WC/CTL or	$1500	
Dual redundant link	$2800	
Total Hardware Cost per Host		$3150-5950
TCP/IP Software		$300-15,000
4.1 BSD Unix Driver including TCP/IP (from BBN) or		$300
RSX-11M Driver	$850	
TCP/IP or	?	
RT-11 Driver	$650	
TCP/IP or	?	
VMS Driver	$ 950	
TCP/IP (from DTI)	$15,000	
Total Cost per Host		$3450-20,950
General Network Components		
WC/08	$1100	
with remote indicator	$1220	
WC/16	$1800	
with remote indicator	$2040	
TIU/2	$7200	
TIU/8	$8200	
TIU/16	$9500	
FL/WC/WC	$1600	
Dual redundant link	$2900	
RE/WC/WC	$500	

2.6 AEROSPACE PHYSICAL PLANT RESTRICTIONS

The restrictions of the existing facilities at Aerospace and some alternative solutions to existing problems are discussed in this section. The most important links in this system are the interbuilding conduits, specifically, two conduits from A3 to A6, six conduits from A3 to A2 inside the AGO

complex. two conduits from A2 to D8. and four conduits across Aviation Boulevard from A2 to the buildings on the LAAFS site.

1. A3 to A6 - Facilities just finished pulling coaxial cables through these conduits to service terminals located throughout the laboratories. They report that these conduits are now so full that further pulls of any cables will be extremely difficult. Some 7 to 8 RG-62 75 ohm coaxial cables remained unused. Two of these cables have been reserved for use in the network.

2. A3 to A2 - These conduits are the central nervous system of AGO. As one might expect the conduits are completely full. No further cable pulls are possible without first emptying them of unused cables. However. an alternative route via an outside cable tray running along the third floor ledge of A1 is available.

3. A2 to D8 - These conduits are in very good shape. There is one conduit containing approximately 30 unused fiber optic strands and two 25-pair twisted pair metallic wires. Some fibers and wires are available for use. These cables actually run from A3 (1020) to D8. The other conduit is completely empty. This empty conduit is accessible from A2. Its use will have to be carefully planned with the good of the entire company in mind.

4. A2 to LAAFS building - Two of the conduits passing under Aviation Boulevard are filled with IPD wires and telephone wires. The other two conduits contain the terminated remnants of old Security wiring. One of the conduits holds six old CATV segments that run from the A2 basement to a manhole between buildings 100 and 125 on the LAAFS side. The other one contains the wiring for a remote surveillance and alarm system for LAAFS that dates back twenty years to the time when Aerospace had responsibility for LAAFS security. Security has been asked about releasing the conduits for other uses. They will release one of the conduits for a local network if it is approved as a corporate requirement.

3. IMPLEMENTATION PLAN

The Aerospace environment (i.e., interbuilding distances of up to 1 km) has dictated that proNET be used for at least the interbuilding communication. The wide acceptance of Ethernet among manufacturers suggests that Ethernet be used wherever possible because of expected manufacturer support and reduced costs. Ethernet (the 10 Mbps variety) is relatively new. and not all specified hardware exists (most notably the distance extending repeaters and remote repeaters).

The initial network will connect together the CAD VAX in D8. the ISRO VAX in A2, the APL 11/34 in 130 and a PDP 11/23 Gateway into the ARPANET. The initial network itself will consist of a set of proNET components. The next step will be to link building A6 into the network and to install gateways and Ethernets in each of the buildings.

The main wire center will be in A3/1020. From there, buildings D8 and 130 will be linked via fiber optic cable and building A2 via twin-axial cable. The D8 link will use an existing unused pair of fibers. while new cables must be installed to serve 130 and A2. Building 130 will be served using the existing conduit under Aviation Boulevard. The conduit will first be emptied and then new fiber optic cable will be pulled. A2 will be served by running twin-axial cable from A3/1020 up through the roof to the cable tray on the outside of the third floor of A1, then down through the roof of A2 and into the ISRO VAX machine room.

The initial network will be deployed in a sequence of five phases to allow thorough testing of individual components. The phases are briefly described below and are illustrated in Figures 3-1 through 3-6.

- 0.1. Create a single node proNET network with the ISRO VAX connected to a WC/08 via twisted pair. then twin-axial (about 300m) and then a pair of RG-62 coaxial cable (about 300m).

- 0.2. Install a WC/16 and test it by connecting the two WC via the twin-axial cable.

- 0.3. Install a DEC PDP 11/23 gateway machine with appropriate interfaces. This will be attached to the WC through twisted pair and to the ARPANET through the current ISRO VAX ARPANET connection through the ECUs.

Phases 0.2 and 0.3 may be interchanged depending on hardware availability. Phase 0 will take place entirely within the ISRO VAX machine room.

- 1.0. Install the WC/16 in its permanent location in A3/1020 and retest it. Then connect the CAD VAX via existing fiber optic cable. using the Unix software from ISRO to test the

hardware (FL/WC/CTL). After successful hardware testing. the VMS TCP/IP software (from DTI) can be tested.

Following phase 1.0 we will have direct communication between the VAX machines and access for both machines to the ARPANET.

- 2.0. After the installation of cables from A3 to 130. reconnect the ISRO VAX to the ARPANET for interim access and then move the WC/08 and gateway to building 130. connect the APL 11/34 to that WC. and plug the gateway into the WC and the IMP. (This may require an additional port on the IMP.)

The timing of the phases depends on the arrival date of hardware and software. It is difficult to predict when equipment will arrive. Equipment should begin to arrive in November 1982. All the hardware items listed in Table 3-1 should arrive prior to February 1983. Our wish is to begin phase 0.1 in December 1982 and complete phase 2.0 by April 1983. We will then have reached our initial local network.

A breakdown of the component costs associated with this implementation is given in Table 3-1. All hardware items in Table 3-1 have been ordered. We already have the TCP/IP software for VAX Unix. having paid the $300 copy charge for the software when the ISRO VAX was connected to the ARPANET. This software included a proNET driver in addition to the ARPANET driver. The cost of the software for the Gateway and the APL 11 is unknown. This software will be available in the public domain, and therefore the cost will be low as it was for the ISRO VAX software.

The Phase 3.0 network might be logically configured as in Figure 3-7 with the IPD computers connected. building A6 on the proNET. and an Ethernet installed in building A6. This will provide the general computing services of IPD over the network. The exact method of connection and therefore the cost of connecting the IPD machines is not yet determined. The Ethernet in building A6 will allow the connection of much more of the Laboratory Operations' computing equipment to the network. Today's hardware cost of expansion to A6 with an 11/23 Gateway and Ethernet connection of the PDQ-3 is approximately $16.000. The Gateway software is available in the public domain. The PDQ-3 software is yet to be developed (by Aerospace or by the PDQ-3 manufacturer).

In Phase 4.0 we will likely connect the Lab VAX to the network. We show the Lab VAX being connected to the A6 Ethernet in Figure 3-8. Today's cost for this connection is $2970 for hardware and $7025 for software. This is not the only possible connection. The Lab VAX could be attached directly to the WC in A6. This choice costs $3150 for hardware. and the software (a copy of the ISRO VAX software) is free. Clearly. if the decision were to be made today. the latter is the better choice.

Table 3-1: Initial Network Costs

Initial Network Costs		
CAD VAX		$19.950
HSBU/CTL	$3150	
FL/WC/CTL	$1500	
TCP/IP Software (DTI. proNET driver from O'Dell)	$15.300	
ISRO VAX		$3150
HSBU/CTL	$3150	
TCP/IP Software	$0	
APL 11		$3150
HSBU/CTL	$3150	
PDP 11/34 RSX proNET TCP/IP (Mike O'Dell LBL)	?	
Gateway		$15.450
DEC		
11/23-AA	$6500	
Proteon		
HSBQ/CTL	$3150	
ACC		
IF-11Q/1822	$3500	
Robustness Module	$1400	
Modified Boot-Diagnostic Modual	$500	
Multipurpose Back Panel	$250	
IF-11Q/1822 Back Plane Cable	$150	
BBN		
ARPANET-proNET Gateway Software	?	
General Network Components		$4860
WC/16 in A3	$2040	
WC/08 in 130	$1220	
FL/WC/WC from A3 to 130	$1600	
Total Cost		$46.560

The network also makes it possible to locate the machine in A2. A3. D8. or 130 instead of in A6. Phase 4.0 may also add Ethernets in some other buildings.

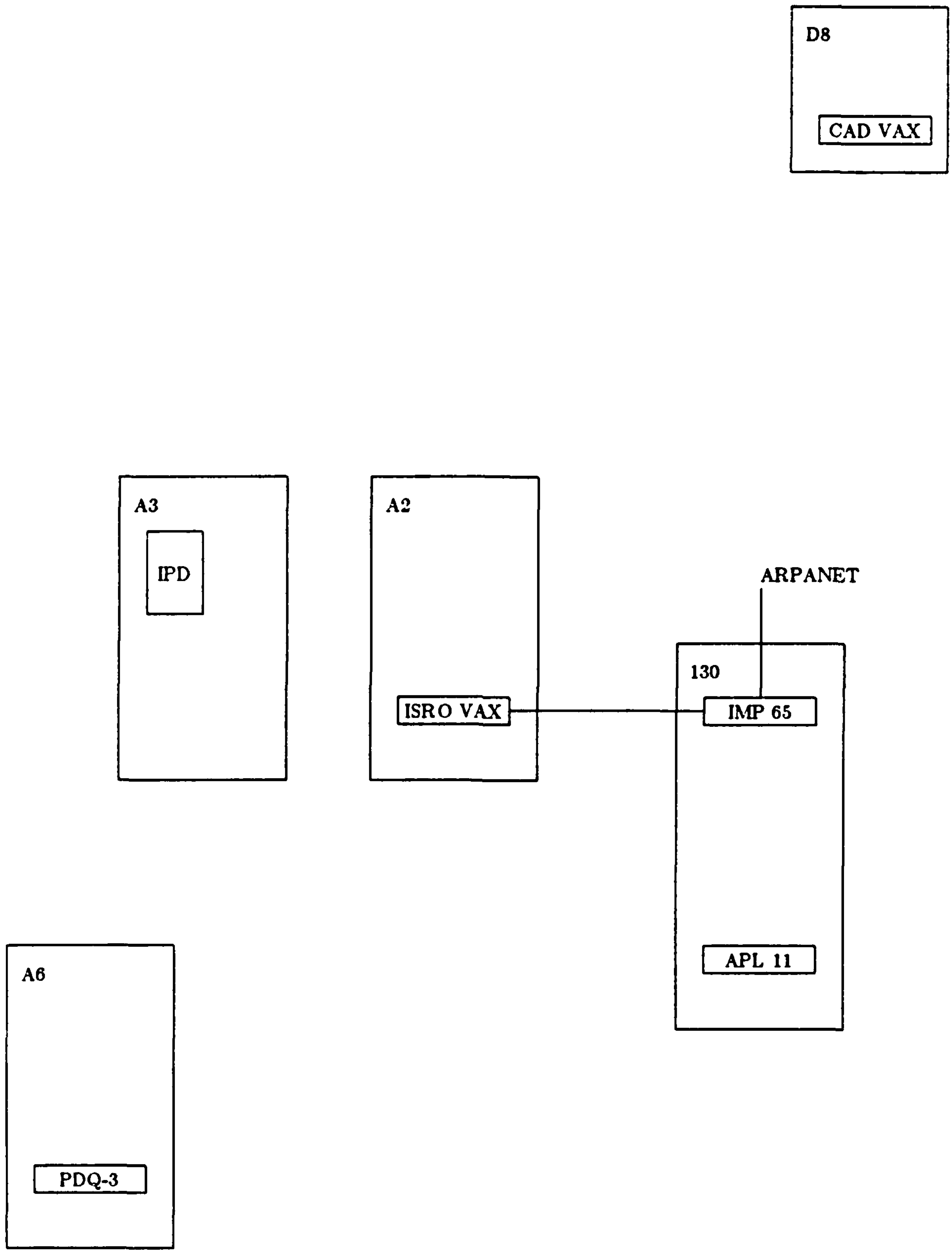

Figure 3-1: Some Existing Resources

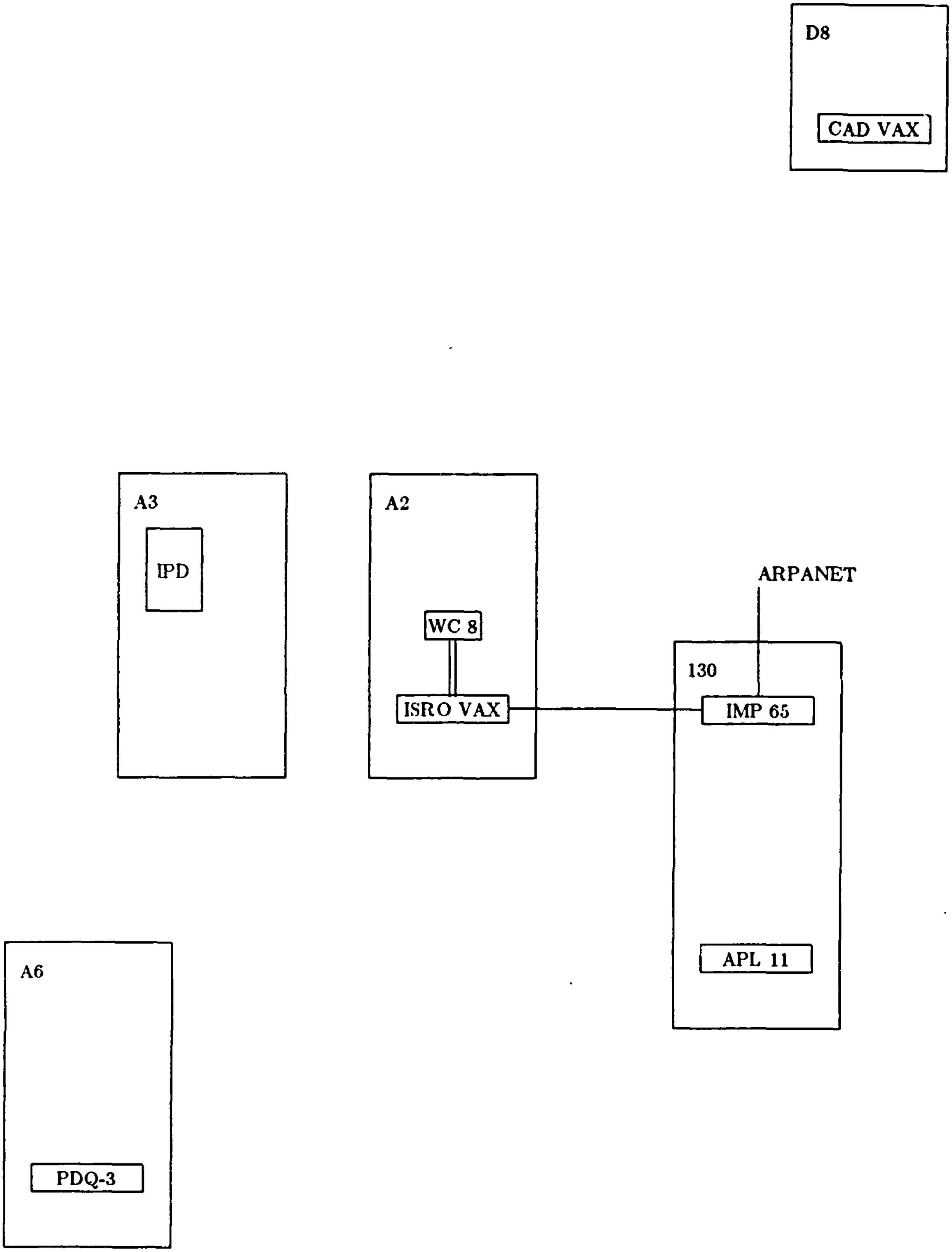

Figure 3-2: Phase 0.1

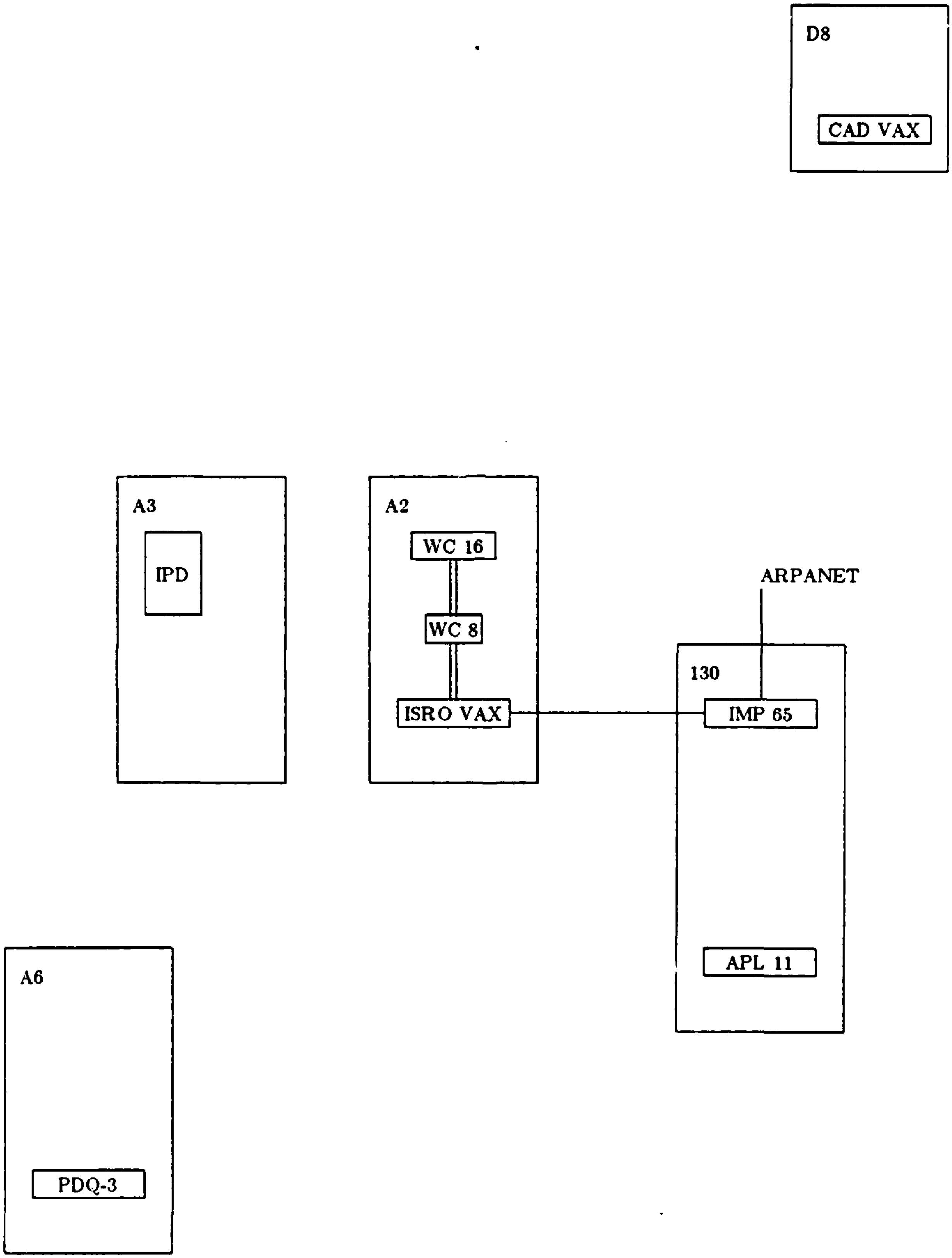

Figure 3-3: Phase 0.2

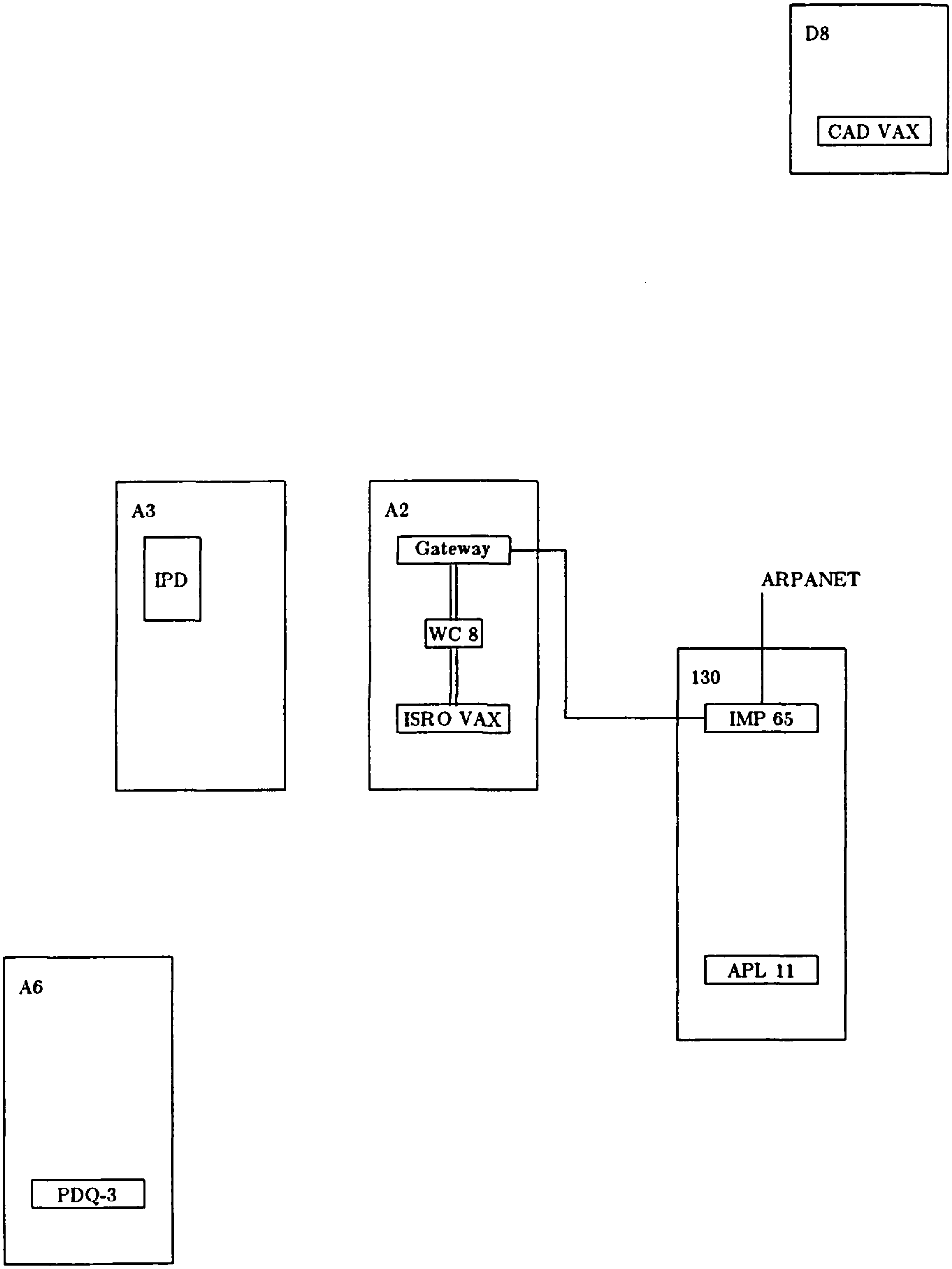

Figure 3-4: Phase 0.3

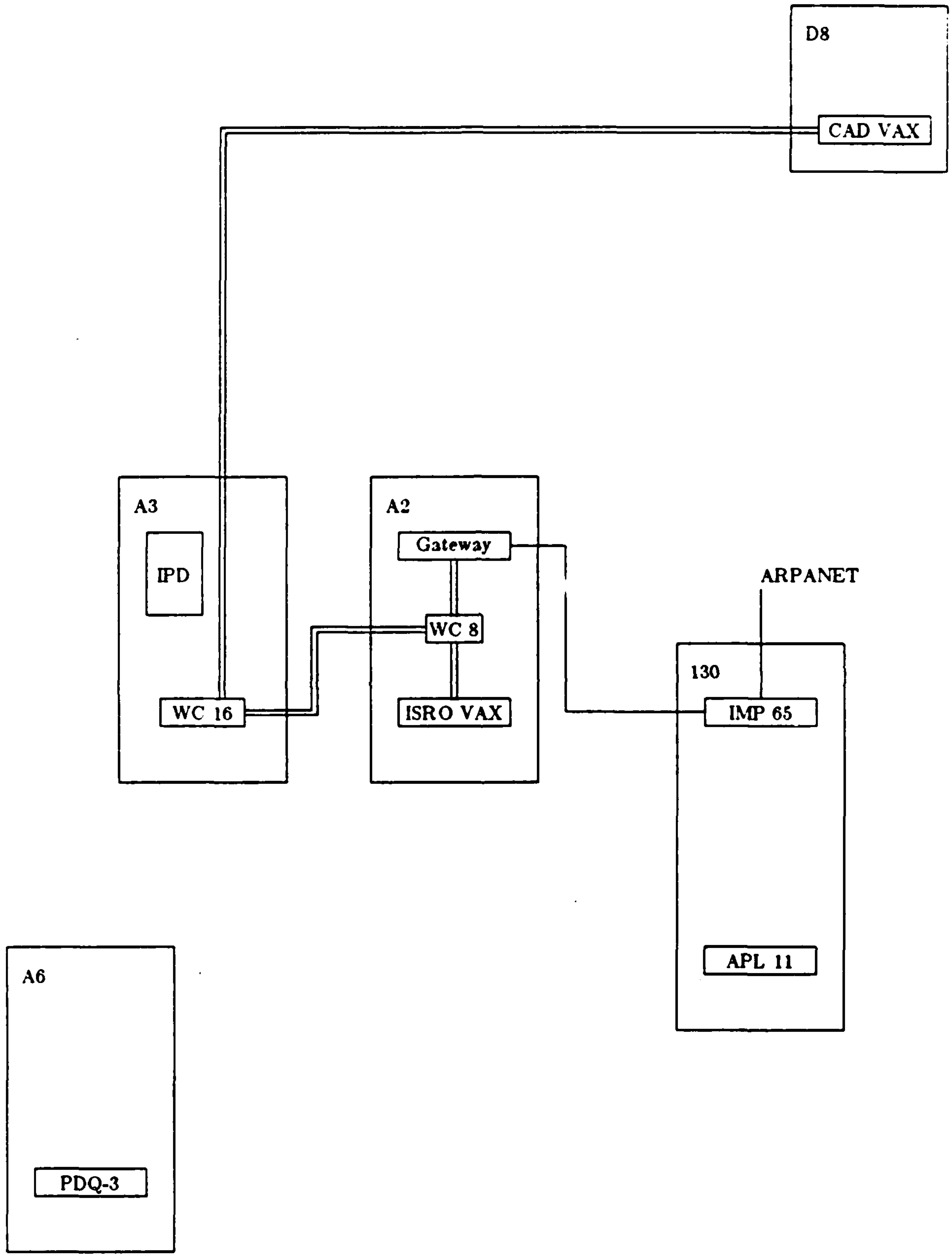

Figure 3-5: Phase 1.0

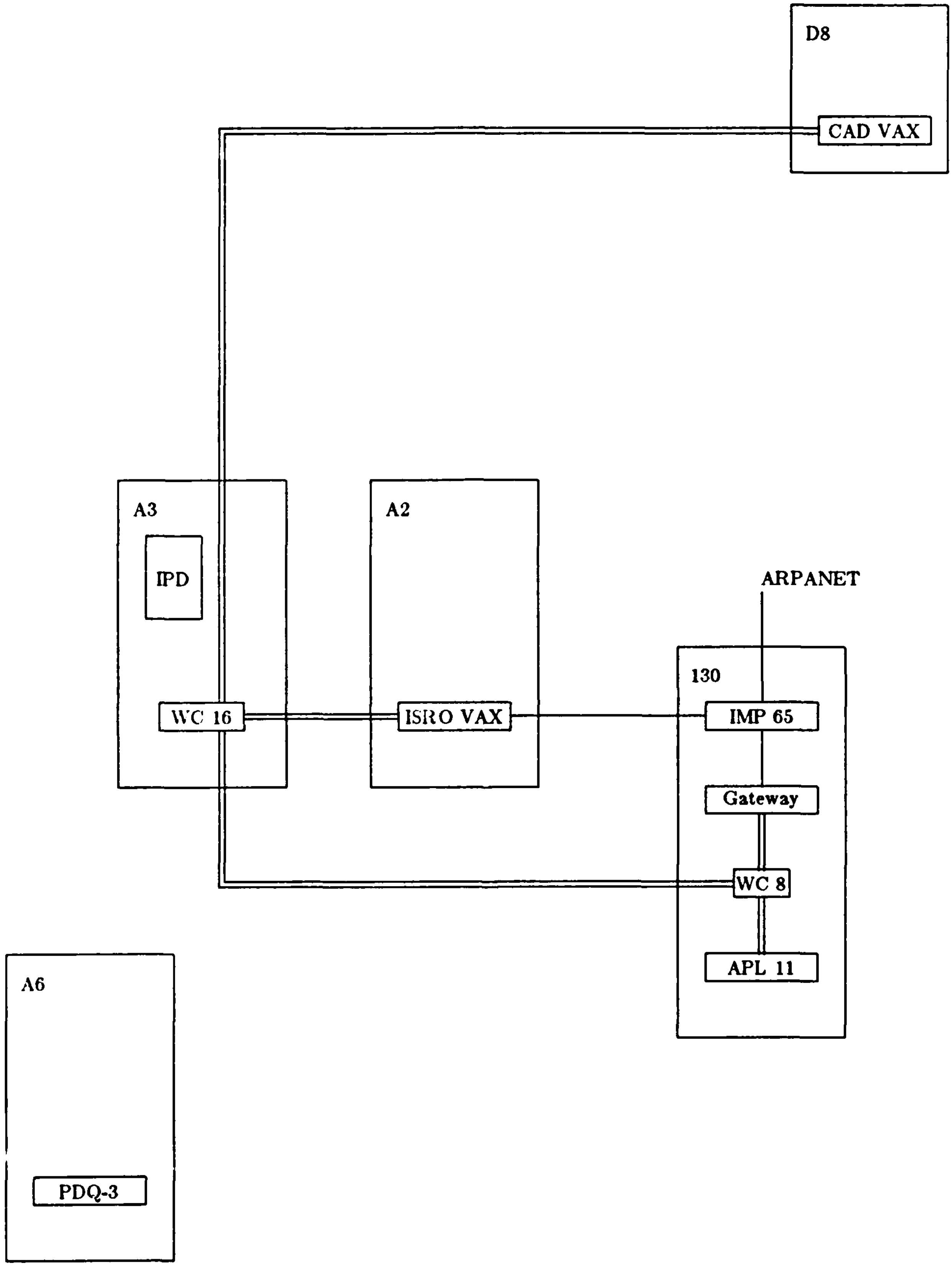

Figure 3-6: Phase 2.0

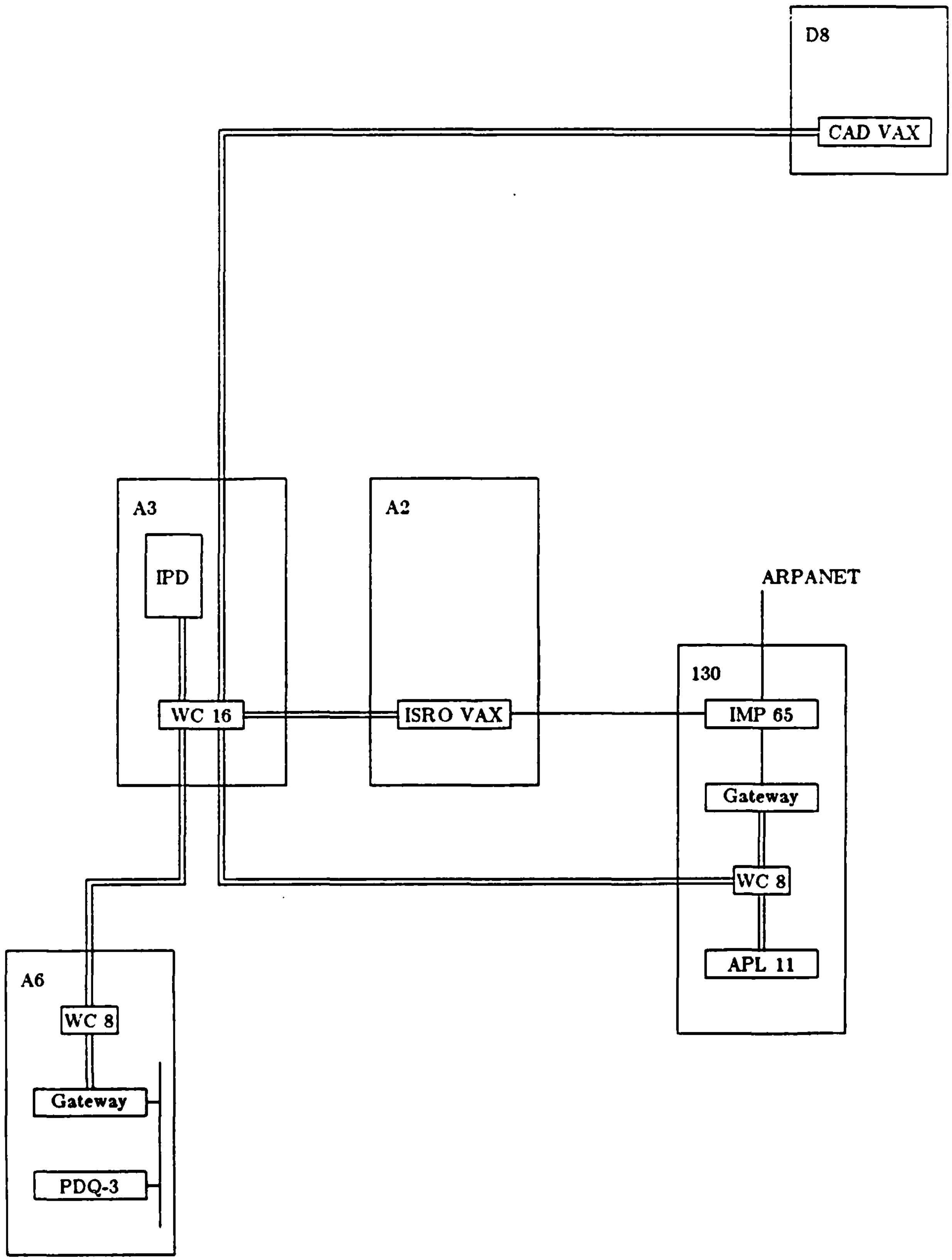

Figure 3-7: Possible Phase 3.0

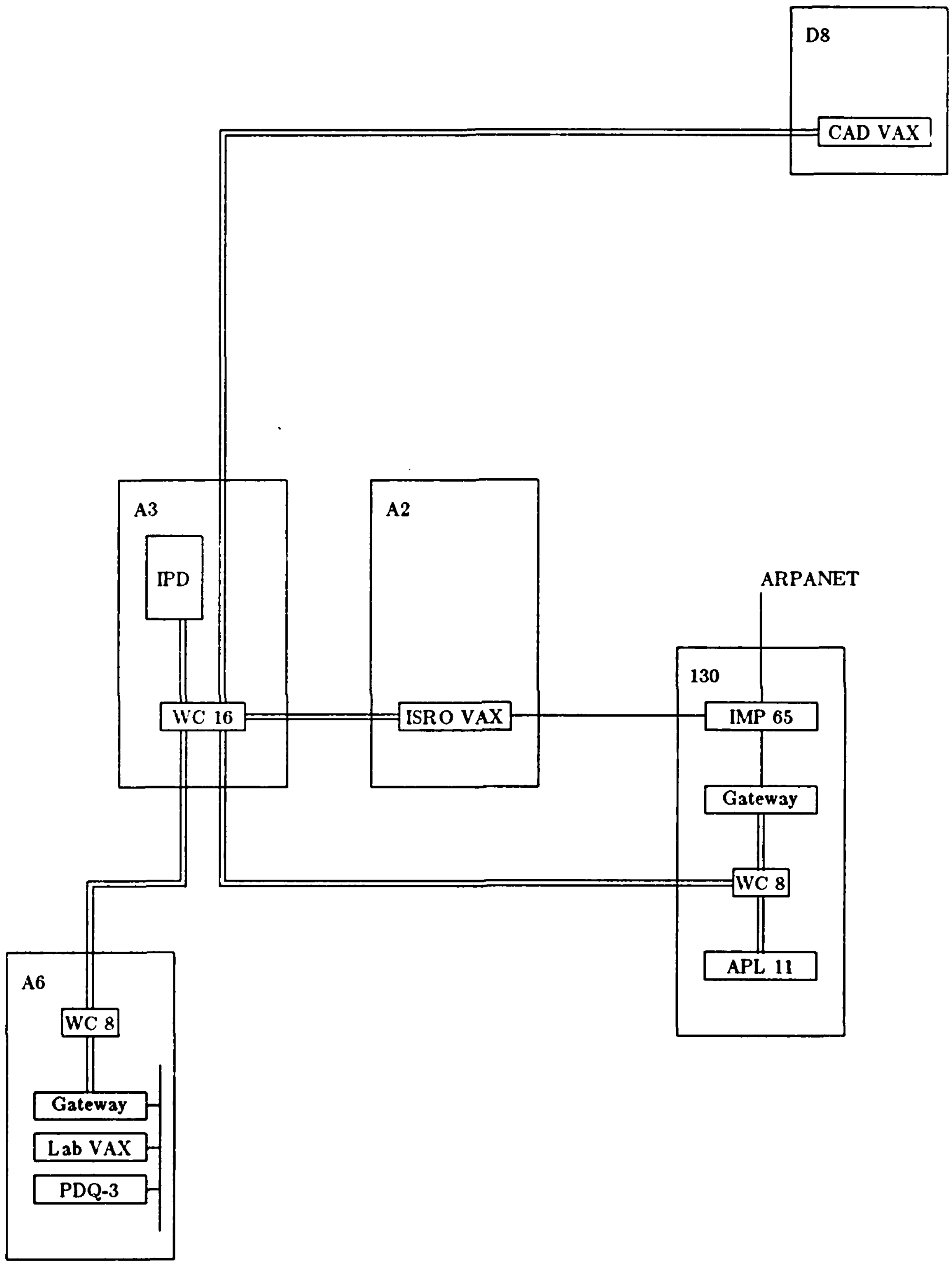

Figure 3-8: Possible Phase 4.0

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I. APPENDIX: HOSTS

For each host section, the following information will be given:

- System configuration
  - Hardware
  - Op Sys
  - Peripherals
  - Software
- Intended use of local net
  - Services to be provided to others
  - Uses of other resources
- Hardware required
  - Controller
  - Transceiver
- Software required
  - IP/TCP
  - Services
- Person responsible for providing software and hardware support

1.1 CAD VAX

- Hardware
  - VAX 11/780 CPU. 4 Megabytes of memory
- Peripherals
  - 1200 Megabytes of disk storage
  - TE16 tape drive 800/1600 bpi 45 ips
  - TU45 tape drive 1600/6250 bpi 75 ips
  - LP-11 600 lpm 132 col.
  - Assorted CAD equipment
- Operating System
  - VMS 3.0
- Software
  - VOS tools (80% of all Unix commands) and CAD tools
- Network Use
  - The CAD VAX offers general computing. CAD/CAM software. image processing and special graphics software to users of the network. Many CAD VAX users require use of the ARPANET for, among other things. the VLSI fabrication facility. Some CAD VAX users require use of the IPD computing equipment.
- Hardware Required
  - One CTL/HSBU ($3150) and one FL/WC/CTL ($1500) from Proteon
  - Total cost $4650.
- Software Required
  - TCP/IP software for VMS from DTI ($15000) with a proNET driver from Mike O'Dell (LBL) (nominal charge approximately $300)
  - Total cost $15300.
- Person Responsible
  - A. W. Sills

I.2 ISRO VAX

- Hardware
  - VAX 11/780 CPU
  - 8 Megabytes of memory
- Peripherals
  - 472 Megabytes of disk storage (soon to be 3000)
  - Imagen printer
  - Xerox Penguin printer
- Operating System
  - Berkeley Standard (BSD) Unix Version 4.1
- Software
  - Interlisp
  - Scribe
- Network Use
  - The ISRO VAX offers general computing. text editing. electronic mail service. file storage and high quality text printing to users of the network. Many ISRO VAX users require use of the ARPANET. Some ISRO VAX users require access to the CAD software of the CAD VAX. Some ISRO VAX users require use of the IPD computing equipment.
- Hardware Required
  - One CTL/HSBU ($3150) from Proteon
  - Total cost $3150.
- Software Required
  - None (we already have TCP/IP. Telnet. FTP. etc. with drivers for ARPANET and proNET)
  - Total cost $0.
- Person Responsible
  - L. C. Nelson

I.3 APL PDP-11

- Hardware
  - DEC PDP 11/34 CPU, 256 Kilobytes of core memory
- Peripherals
  - Dual 10 Megabyte RL02 disks
  - Dual 5 Megabyte RX02 floppy disks
  - 160 Megabyte Winchester disk
  - Dual density magnetic tape drive
  - Quantex digital image processor
- Operating System
  - RSX or RT-11
- Software
  - DEC Assembly, FORTRAN, Basic, Pascal
- Network Use
  - Service provided by the APL 11 will be limited to off hours. APL 11 users require access to to a large core memory machine for number crunching tasks and to the image processing and graphics software of the CAD VAX.
- Hardware Required
  - One CTL/HSBU ($3150) from Proteon
  - Total cost $3150.
- Software Required
  - TCP/IP software for RSX and RT-11 with a proNET driver (nominal charge unknown)
  - Total cost (unknown nominal charge)
- Person Responsible
  - G. I. Segal

I.4 GATEWAY TO ARPANET

- Hardware
  - DEC PDP 11/23 CPU
  - 128 Kilobytes of core memory
  - ACC IF-11Q/1822 etc ARPANET interface
  - Proteon HSBQ/CTL
- Peripherals
  - None
- Operating System
  - Gateway software from BBN runs stand alone
- Network Use
  - The gateway provides the primary interface between the Aerospace local area network and the ARPANET.
- Hardware Required
  - All new hardware
  - Total cost $15450.
- Software Required
  - Gateway software from BBN (nominal charge uknown)
  - Total cost (unknown nominal charge).
- Person Responsible
  - L. C. Nelson

I.5 SSL PDQ-3

- Hardware
  - P-code microengine CPU
  - 128 Kilobytes of memory
  - Q-bus backplane
- Peripherals
  - 30 Megabytes of hard disk storage
  - 1 Megabyte of floppy disk storage
  - Special purpose I/O gear
- Operating System
  - UCSD Pascal iii language/operating system
- Network Use
  - The PDQ-3 offers no service to users of the network. It is a user host. Some PDQ-3 users require use of the ISRO VAX. Some PDQ-3 users require use of the IPD computing equipment.
- Hardware Required
  - One CTL/HSBQ from Proteon or one Q-bus Ethernet controller and one Ethernet transceiver.
- Software Required
  - TCP/IP software for the PDQ-3 with proNET or Ethernet driver User Telnet and User FTP are also required.
- Person Responsible
  - D. K. Stone

I.6 IPD COMPUTERS

- Hardware
  - IBM 3033. CDC 730. CDC 720. CDC 7600. CDC 176
- Peripherals
  - Too many to list here
- Operating System
  - Several
- Software
  - More than can be listed here
- Network Use
  - The IBM mainframe supports TSO and SPF as well as special utility packages of many types. The CDC mainframes support high-speed number crunching and special utility packages that Aerospace has used for many years. These are the computers that many smaller minicomputers and microcomputers will access to analyze and/or reduce their gathered data.
  - The CDC machines are linked to each other by an extensive network of channel-to-channel connectors that effect high-speed communication between the processors. The 720 is linked to the 3033 by coaxial cable. There is Aerospace-written software that allows files and jobs to be transferred between the two computer systems.
  - Auscom makes a unit that allows a VAX computer to communicate with an IBM 3033. and transfer files at 1 Mbps. The unit mimics a 327X-type controller to the 3033. The Auscom unit is also capable of communicating to proNET. Auscom has not yet completed a driver for proNET. but they offer a subset of IP for their device.
- Hardware Required
  - One CTL/HSBQ from Proteon ($3150) or Auscom. one 8911 unit from Auscom. Inc. and one interface card for the VAX from Able or Ranyan
- Software Required
  - Aries Operating System from Auscom and a driver for proNET
- Person Responsible
  - A. W. Sills

LABORATORY OPERATIONS

The Laboratory Operations of The Aerospace Corporation is conducting experimental and theoretical investigations necessary for the evaluation and application of scientific advances to new military space systems. Versatility and flexibility have been developed to a high degree by the laboratory personnel in dealing with the many problems encountered in the nation's rapidly developing space systems. Expertise in the latest scientific developments is vital to the accomplishment of tasks related to these problems. The laboratories that contribute to this research are:

Aerophysics Laboratory: Launch vehicle and reentry fluid mechanics, heat transfer and flight dynamics; chemical and electric propulsion, propellant chemistry, environmental hazards, trace detection; spacecraft structural mechanics, contamination, thermal and structural control; high temperature thermomechanics, gas kinetics and radiation; cw and pulsed laser development including chemical kinetics, spectroscopy, optical resonators, beam control, atmospheric propagation, laser effects and countermeasures.

Chemistry and Physics Laboratory: Atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions and radiation transport in rocket plumes, applied laser spectroscopy, laser chemistry, laser optoelectronics, solar cell physics, battery electrochemistry, space vacuum and radiation effects on materials, lubrication and surface phenomena, thermionic emission, photosensitive materials and detectors, atomic frequency standards, and environmental chemistry.

Computer Science Laboratory: Program verification, program translation, performance-sensitive system design, distributed architectures for spaceborne computers, fault-tolerant computer systems, artificial intelligence and microelectronics applications.

Electronics Research Laboratory: Microelectronics, GaAs low noise and power devices, semiconductor lasers, electromagnetic and optical propagation phenomena, quantum electronics, laser communications, lidar, and electro-optics; communication sciences, applied electronics, semiconductor crystal and device physics, radiometric imaging; millimeter wave, microwave technology, and RF systems research.

Materials Sciences Laboratory: Development of new materials: metal matrix composites, polymers, and new forms of carbon; nondestructive evaluation, component failure analysis and reliability; fracture mechanics and stress corrosion; analysis and evaluation of materials at cryogenic and elevated temperatures as well as in space and enemy-induced environments.

Space Sciences Laboratory: Magnetospheric, auroral and cosmic ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing using atmospheric radiation; solar physics, infrared astronomy, infrared signature analysis; effects of solar activity, magnetic storms and nuclear explosions on the earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; space instrumentation.

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